THINGS of science

CHEMICAL INDICATORS

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CHEMICAL INDICATORS

It has long been known that certain substances change color when others are added to them. That coloring materials extracted from vegetables, bark, flowers, insects and earthy materials may change their hues when treated in various ways was known to even primitive tribes. For example, it was common knowledge for centuries that solutions of colors extracted from certain blue flowers turned red on the addition of vinegar or lemon juice. However, it was not until about 1663 that this reddening property was shown to belong to all acids by the English natural scientist, Robert Boyle (1627-1691). This marked the start of an investigation into chemical indicators.

Today, many indicators of extreme sensitivity are used for a variety of testing purposes. For convenience many of the indicators are prepared on paper strips. High grade filter paper is saturated with the indicator (in the more simple forms) and then dried. The paper, cut into narrow strips, is used in a number of different ways.

In this unit we have included some of the typical indicator or test papers commonly used in laboratories. You will learn

their uses and discover many interesting facts by doing the experiments.

First identify your specimens. Be sure your hands are clean and dry when handling the test papers. Hold the strips by their edges and avoid touching their surfaces. Notice that some of the papers are packaged in separate bags. The papers are grouped in this manner to avoid their interaction with each other, so be sure to keep the papers in their original bags when not in use.

In one bag:

BLUE LITMUS PAPER—Blue paper; 2 x 4 inches.

PHENOLPHTHALEIN PAPER—White paper; 2 x 4 inches.

TURMERIC PAPER—Yellow paper; 1½ x 3 inches.

In second bag:

RED LITMUS PAPER—Reddish pink paper; 2 x 4 inches.

CONGO RED PAPER—Bright red paper; 1½ x 3 inches.

METHYL ORANGE PAPER—Orange colored paper; 1½ x 3 inches.

In third bag:

WIDE RANGE pH TEST PAPER—

Two orange strips; ¼ x 3¾ inches.

COLOR CHART—For wide range pH test paper.

Unbagged:

POTASSIUM IODIDE STARCH PAPER—White paper; 1½ x 3 inches.

COBALT CHLORIDE PAPER—Pale pink paper (or blue); 1½ x 2 inches.

FILTER PAPER—Large piece of plain white paper for making your own indicator papers.

LITMUS

Litmus is the oldest and most commonly used indicator for acids and bases. It is a mixture of dyes, containing as its chief constituents, the chemicals azolitmin and erythrolitmin. Litmus is obtained from a species of lichens found along the Mediterranean coasts and comes mostly from the Netherlands. The dye is extracted from the lichens by treatment with air, ammonia and alkali carbonate. Litmus can also be synthesized in the laboratory.

Litmus has the property of turning red in an acid solution and blue in a basic or alkaline solution. It is usually used in the form of litmus paper made by

dipping chemically pure absorbent paper into a solution of the dye and then permitting it to dry. The red litmus paper is made by immersing the paper into a slightly acidic solution of litmus and the blue by placing the paper in a slightly alkaline solution of the indicator.

The litmus with which the paper is impregnated works the same as a solution of the substance.

An indicator is usually an organic compound, weakly acidic (or weakly basic) that has one color when it is undissociated or unionized and another color when it is dissociated or ionized. When litmus is in its undissociated form it is red and when dissociated it is blue. The reaction is reversible as shown below:

H is the symbol for hydrogen and In for indicator.

$$\underset{\substack{\text{(undissociated)}\\ \text{red}}}{HIn} \rightleftarrows \underset{\substack{\text{(dissociated)}\\ \text{blue}}}{H^+ + In^-}$$

When red litmus paper is placed in an alkaline solution, the litmus becomes dissociated and therefore turns blue. When blue litmus paper is placed in an acid solution the hydrogen ion (H^+) in the solution reacts with the indicator to pro-

duce the undissociated form and the paper turns red.

This reaction is typical of indicators. They are one color in the undissociated form and assume another color when dissociated.

Acids, bases and salts are three common types of compounds important in the laboratory as well as in the home.

In general an acid is a hydrogen containing compound that dissociates when dissolved in water producing hydrogen ions. For example, hydrochloric acid (HCl) dissociates into hydrogen (H^+) ions and chloride (Cl^-) ions in an aqueous solution.

$$HCl \rightleftharpoons H^+ + Cl^-$$

A base is a substance containing a hydroxide group (OH) and produces hydroxyl ions (OH^-) on solution in water. For example sodium hydroxide (NaOH) ionizes to form sodium (Na^+) and hydroxyl ions in an aqueous solution.

$$NaOH \rightleftharpoons Na^+ + OH^-$$

When an acid and a base are mixed together, they react with each other to form a salt and water.

$$Na^+ + OH^- + H^+ + Cl^- \rightarrow$$
$$Na^+ + Cl^- + H_2O$$

Note that water is produced when an acid and base form a salt. You are all familiar with the chemical formula of water, H_2O. When water ionizes, as it does very slightly, it separates into H^+ and OH^- ions. However, the H^+ and OH^- exactly balance each other and therefore it is neither acidic nor basic but neutral.

(When water ionizes, the hydrogen ion attaches itself to a water molecule forming the hydronium ion, H_3O^+, but in writing chemical reactions, H^+ is usually used to represent the hydronium ion for the sake of simplicity.)

An acid or base may be strong or weak depending upon the extent of its dissociation in water. HCl is a strong acid because it almost completely dissociates into H^+ and Cl^- ions, while acetic acid dissociates only slightly and is a weak acid. Sodium hydroxide is a strong base, while ammonium hydroxide is a weak base.

Because strong acids and bases are corrosive and dangerous to handle except under supervision and laboratory conditions, none of the experiments will include the use of such chemicals.

ACID-BASE INDICATOR

Before you start your experiments, make a chart listing the materials tested, the name of the indicator and the color change produced (Fig. 1).

	Indicator					
Substance tested	blue litmus	red litmus	congo red			
lemon	red					
vinegar						
ammonia						

Fig. 1

Indicators that change color in an acid or basic solution are called acid-base indicators.

Experiment 1. Cut a narrow strip about ⅛ inch wide by two inches long from your blue litmus paper.

Squeeze a little lemon juice into a small glass. Place the tip of the litmus paper, about ⅛ inch, into the lemon juice. What

happens to the color? The change in color to red indicates the presence of an acid. Lemons contain citric acid. The hydronium ion is responsible for the sour taste of acid substances. (The hydrogen ion of the acid combines with water molecules to form hydronium ions.)

Cut off the used tip of litmus paper. Do this after each experiment with your indicator papers so that you will have a fresh end for testing each time.

Fill the glass with water and stir. Dip the end of the litmus paper into the diluted lemon juice. Does it turn red again?

Pour a little of the diluted juice into a glass and fill the glass with water and test it again. Continue to dilute the solution until you get practically no color reaction. Long before this happens, you will not be able to taste the lemon in the diluted juice. You can see how sensitive litmus paper is to the presence of acid.

Experiment 2. Squeeze a little juice from an orange into a dish. Does it turn blue litmus red also? All citrus fruits contain citric acid.

Experiment 3. Make a solution of boric acid, the mild disinfectant used as an eyewash, by dissolving a half a teaspoon of the acid in ¼ cup warm water.

Test it with blue litmus.

Experiment 4. Slice an apple and place the blue litmus against the cut edge. Does the paper turn red? Apples contain malic acid. Other fruits, such as tomatoes, cherries and raspberries also contain malic acid.

Experiment 5. Dissolve an aspirin in ¼ cup of water. The acetyl salicylic acid present in aspirin causes the blue litmus to turn red.

Experiment 6. Make a cup of tea and test it after it has cooled, with blue litmus. The acid in tea is tannic acid, also present in coffee.

Experiment 7. Test ordinary club soda with blue litmus paper. The paper will turn red, but after being exposed to the air for a while, the color turns blue again. The reason for this is that the carbonic acid responsible for the color change vaporizes.

Experiment 8. Now, cut a strip of red litmus ⅛ x 2 inches from your specimen. Dissolve a teaspoon of baking soda (sodium bicarbonate) in ¼ cup water. Dip the tip of the red litmus into the solution. Does it turn blue? Baking soda is mildly alkaline.

Experiment 9. Dissolve a teaspoon of shampoo in ¼ cup of water and test it with the red litmus. Is it alkaline?

Experiment 10. Check detergents and soaps used for laundry with red litmus. Are they alkaline also?

Experiment 11. To half a cup of water add about a teaspoon of household ammonia (ammonium hydroxide). Handle the ammonia very carefully and AVOID BREATHING IN THE FUMES.

Place the tip of the red litmus into the ammonia solution. Does it turn blue? If you place the paper near heat and allow it to dry, the blue color disappears. This is because the ammonia is driven off as a gas.

Experiment 12. Pour a little water from the tap into a glass and check it with red litmus. Do you get a color change? Now test it with blue litmus. Does it turn red? Tap water is usually neutral, but depending upon the minerals present in the water, it may be slightly alkaline or acid in some locations.

Obtain some distilled water. Does either the red or blue litmus change color? Pure water is neutral.

Experiment 13. If your tap water is neutral you can use it for this experiment. Otherwise, use distilled water. Dissolve half a teaspoon of table salt (sodium chloride) in half a cup of water. Test it with blue litmus. Does it change color?

Now test it with red litmus. Does it turn blue? You will find that sodium chloride is neutral, neither acid nor alkaline.

Experiment 14. Repeat the experiment with Epsom salt (magnesium sulfate). Is it neutral also?

Most salts are neutral in aqueous solution.

Experiment 15. Dissolve about ½ teaspoon of washing soda (sodium carbonate), also called sal soda, in ¼ cup water. Dip the tip of blue litmus paper into the solution. Does it change color? Now test it with red litmus. It turns blue.

You may have expected sodium carbonate to be neutral because it is a salt. However, when it is mixed with water, it reacts with it (hydrolyzes) producing hydroxyl ions. Therefore you have a basic reaction.

Experiment 16. Mix a teaspoon of vinegar with ¼ cup water. Test it with red litmus. Does it change color? The result shows that vinegar is not alkaline, but you will have to test it further to see whether it is an acid or neutral. Check the solution with blue litmus. Now you can be sure it is an acid. Vinegar is acetic acid.

From this experiment and the preceding ones, you can see that neither the blue

litmus nor the red litmus alone is sufficient to determine the nature of a solution. In order to draw a conclusion you need both.

Experiment 17. Put a small strip of both the blue and red litmus papers into your mouth. Examine the papers. You may be surprised to discover that saliva changes the color of both litmus papers. This is because saliva is amphoteric. That is, it has the capacity of behaving either as an acid or base.

Experiment 18. Test other materials such as various types of soil, lime juice, grape juice, rubbing alcohol, witch hazel, sour milk and liquid soap.

Test water in which vegetables have been cooked. Some vegetables, such as spinach, contain oxalic acid.

Experiment 19. Dissolve ½ teaspoon of washing soda in a glass of water. Place red litmus paper in the solution. Allow the litmus which has turned blue to dry. Then dip the blue portion of the strip into vinegar. You again have red litmus. You may repeat this procedure several times.

You have demonstrated that the reaction of litmus is reversible.

Experiment 20. You can make neutral litmus paper which will turn red in acid

and blue in a base solution from your red and blue litmus papers.

Put a few drops of vinegar into a glass of water. Dilute portions of this until a strip of blue litmus barely turns lavender. Do the same using a solution of washing soda diluted until a strip of red litmus paper becomes a pale lavender. Completely immerse these strips in their solutions. Allow them to dry by hanging them with pins so they will not touch any surface.

Place the tip of one neutral litmus paper in an acid. Does it turn red? Cut the used part off and dip the tip into a base. Does it turn blue? Cut the tip off again and place it in distilled water. Does it change color at all?

With neutral litmus paper, you can determine whether a solution is acid, base or neutral immediately.

Experiment 21. Mix one teaspoon of vinegar in ¼ cup water and stir the solution well. Label the container, "acid."

Using another teaspoon, mix one teaspoon of ammonia with one teaspoon of water and label the container, "base." Keep the spoons for the acid and base separate.

Now dip the tip of a strip of blue litmus cut ⅛-inch wide into the acid. Cut off the used part and set it aside. Add about 10

drops of the ammonia to the vinegar and stir the solution. If you have an eye dropper, it will be helpful, but if you are careful, your spoon will serve just as well to add the drops of ammonia to the vinegar. Test the vinegar with litmus again. Cut the tip off and place it next to the first piece.

Add about ten more drops and test the vinegar again. Cut off the tip and place it beside the second piece. Repeat this process, keeping track of the number of drops added, noting the gradual change in the color of the litmus. As you proceed with the experiment reduce the number of drops of ammonia added. When the color change of the blue litmus becomes very slight, add only one drop of the ammonia at a time.

Finally you will reach a point when no change at all occurs in the litmus. The solution is then neutral. This point of neutralization is called the end point.

As you can see from the litmus reaction, the acetic acid was gradually neutralized by the ammonia.

This gradual neutralization of one solution by another is known as titration. This process in a much more precise form is used by chemists to determine exactly the acidity of a solution.

Experiment 22. Reverse the process. Make a weak solution of ammonia, by mixing one teaspoon of ammonia with one-fourth cup water. Add drops of acetic acid solution, made by mixing one teaspoon of vinegar with one teaspoon of water, to the ammonia using red litmus for the titration this time. Make a record of your results.

ACIDITY AND ALKALINITY

You have determined with your litmus papers, whether a solution was acid, alkaline or neutral. But these observations do not indicate the concentration of the acid or base. However, there are test papers with indicators that change color within certain concentrations of acid.

The measure of the acidity of a solution is the hydrogen ion concentration and is usually expressed in moles per liter of solution. (A mole of any substance is its molecular weight expressed in grams.)

Chemists when referring to the hydrogen ion concentration, use the symbol pH. Instead of saying that the hydrogen ion concentration of water is 1.0×10^{-7} mole per liter of solution ($10^{-7} = 0.0000001$), they speak of it as pH 7.

At pH7 the hydroxyl ion concentration of the water is also 1.0×10^{-7}.

For those of you who are interested in the derivation of pH, the symbol is defined as the negative logarithm of the hydrogen ion concentration, or $pH = -\log[H^+]$. Thus, if the hydrogen ion concentration is equal to 1.0×10^{-3} or .001, $pH = -\log 10^{-3} = -(-3)$ or 3. If pH = 4, then the hydrogen ion concentration is 10 times less or 0.0001, since $pH\ 4 = -\log 10^{-4}$.

pH		H ion concentration
0	↑	1.0
1		0.1
2		0.01
3		0.001
4		0.0001
5		0.00001
6	acid	0.000001
7	neutral	0.0000001
8	alkaline	0.00000001
9		0.000000001
10		0.0000000001
11		0.00000000001
12		0.000000000001
13		0.0000000000001
14	↓	0.00000000000001

Table 1

You can see therefore, that the pH decreases as the hydrogen ion concentration increases. The lower the pH, the greater the acidity and the higher the pH, the greater the alkalinity. At pH 7 a solution is neutral. (Note that $[H^+] \times [OH^-] = 10^{-14}$ for any aqueous solution at 25°C.)

Table 1 shows the hydrogen ion concentration at pH values from 0 to 14.

DETERMINING pH

Experiment 23. Cut a narrow strip from your congo red paper and dip it into vinegar. The paper turns a deep blue in acid. Congo red paper changes color when a solution has a pH of 3.0 to 5.2.

Experiment 24. Place a strip of methyl orange paper in lemon juice. Does it turn red? Methyl orange is an indicator for the pH range of 3.1 to 4.4.

Experiment 25. Test vinegar with a narrow strip of your phenolphthalein paper. Is there any color change? Now dip it in a solution of washing soda. Does it turn red? Phenolphthalein turns red in solutions of pH 8.0 to 10.0.

Experiment 26. Note the deep yellow color of your turmeric paper. Turmeric is extracted from the rhizome of the plant *Curcuma longa* and its origin is the same

as that of Indian saffron or curry.

Place the tip of a strip of turmeric paper in vinegar. What happens? No change in color occurs. Turmeric reacts in solutions of pH 7.8 to 9.2. Dip it in ammonia. Does it turn brownish red?

Experiment 27. Cut strips about 1½ inches long by ¼ inch wide of congo red, turmeric, methyl orange, phenolphthalein and blue and red litmus papers.

In a small dish make a dilute acid solution by adding about one teaspoon of vinegar to ¼ cup of water.

Dissolve a half a teaspoon of washing soda in one-fourth cup water.

Dip one end of each of the indicators in the vinegar solution. Note any color changes.

Add the sodium carbonate solution to the vinegar drop by drop stirring as you do so. Note when each of the indicators changes color. Refer to the pH range of each indicator. Do they change in the sequences expected? As the base is added and the acidity decreases, the pH of the solution is increased. Methyl orange returns to its original color first, next, the congo red, and then the blue litmus turns blue again. The solution is then about neutral. With the addition of more sodium carbonate, the red litmus turns blue, then

the turmeric paper becomes a brownish red and finally, phenolphthalein will show an alkaline reaction.

Experiment 28. Reverse the experiment by cutting additional strips of the papers and placing them in an ammonia solution of one teaspoon ammonia to ¼ cup water. Add vinegar gradually and note your results.

UNIVERSAL INDICATOR

The universal indicator is composed of a series of dyes which change color at specific pH's. Note the color chart included with the wide range pH paper showing the different color changes that occur at the pH indicated. This chart was reproduced by permission of the LaMotte Chemical Co.

Experiment 29. Test different solutions with this paper and then compare the colors to find the pH. Cut each strip down the center making four ⅛-inch pieces.

The pH range of some common substances are given below. Check them using the wide range pH paper and the color chart.

Vinegar pH 2.3
Lemon juice pH 2.2 to 2.4
Fruit jams pH 3.5 to 4.0

Spinach juice pH 5.1 to 5.7
Tap water pH 6.5 to 8.0
Shampoo pH about 9.0

Find the pH of various solutions of other substances.

MAKE YOUR OWN INDICATORS

Fruits and flowers make excellent indicators. Using your indicators as references, make solutions of acids and bases of known pH ranges and label each solution. Use these as "standard" solutions to determine the pH range of the indicator papers you will make.

To make the test paper, use the white neutral filter paper in your unit. Dip pieces of the paper into as many of the following liquids as you are able to prepare, then hang the papers up to dry. Each of these liquids is an acid-base indicator. Test the papers against your standard solutions and record the color in acid, the color in alkali and the approximate pH at which they change.

(a) Juice of red cherries turns green with alkalies; red with acids.

(b) An extract of huckleberries turns bluish-gray with alkalies; red with acids.

(c) Tincture of blue hyacinth flowers turns green with ammonia vapors.

(d) A water extract of the common blue iris is green in alkalies; red in acids; blue when neutral.

(e) An infusion of red rose petals turns bright green with alkalies; pink with acids.

(f) Steep leaves of red cabbage in water. Add to this the white of an egg. Apply the mixture to paper. This becomes green with alkalies and red-violet with acids.

(g) Steep some black tea. Tea turns lighter in acid and a dark brown with a base.

(h) Violets. Cut several dozen purple violets into tiny pieces. Pour about a half cup of boiling water over them and allow the mixture to stand. You will obtain a deep greenish-blue solution which will turn green with bases and red with acids.

Experiment 30. Test the dyes of other flowers you may have available noting which make good indicators and which do not.

OTHER TYPES OF INDICATORS

Indicators have been devised for testing a variety of other conditions, such as temperature, oxidation-reduction, humidity, presence of sugar, and for medical testing.

In this unit we have included potassium

iodide starch paper for testing oxidizers and cobalt chloride paper for checking humidity.

Experiment 31. Cut a strip from your potassium iodide starch paper and place it in hydrogen peroxide. Note the color change to dark blue.

Experiment 32. Dip the paper into chlorox. What happens? Chlorox also turns it blue.

Both hydrogen peroxide and chlorine are oxidizers.

Experiment 33. Place a half a teaspoon of scouring powder with blue coloring added in about a tablespoonful of water. Place your potassium iodide starch paper in the solution. Does it turn dark blue? The result indicates the presence of chlorine in the powder.

Experiment 34. Test various laundry soaps for the presence of chlorine.

Experiment 25. Cut a strip from your cobalt chloride paper which will be pink or blue depending on the humidity in your area. Cobalt chloride turns pink in the presence of moisture and blue in a dry environment.

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If it is pink, place the strip of paper in a slow oven (about 200°) for about 15 minutes. Does it turn blue?

If it is blue, place it in a humid area, such as the bathroom or moisten it. Does it turn pink?

Because cobalt chloride turns pink in the presence of moisture and blue when dry, it is helpful in predicting weather. You can make your own weather forecaster by suspending a strip of the cobalt chloride paper by an open window.

When the paper turns blue you will know the weather will be fair. If it turns pink, you may expect rain or very humid weather.

You may wish to investigate the subject of chemical indicators further and learn more about the chemical nature of the indicators and what exactly happens during titration. Elementary chemistry books will be helpful as references.

Appreciation is expressed to Mr. Frank E. Jones, National Bureau of Standards, for reviewing this booklet.

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